# PREPARATION OF SLIDE-TAPE LECTURE PROGRAMS FOR USE IN AERO LABORATORIES

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# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

# THESIS

PREPARATION OF SLIDE-TAPE LECTURE PROGRAMS
FOR USE IN AERO LABORATORIES

by

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# ABSTRACT

Some of the problems usually associated with laboratory courses are overcrowded conditions, improper briefing of students, unavoidable absence, and the lack of standardization in the course structure.

A fully automatic slide-tape lecture program is an acceptable means of minimizing these problems. These presentations are used to introduce background material of a general nature, present instructions for the operation of the necessary equipment, or to brief the students on the objectives, procedures, and desired results of a particular experiment.

A major portion of this thesis is devoted to treating the methods used in the preparation of a typical slide-tape lecture presentation. The objective is to provide a listing of important information relevant to producing slide-tape programs. Also included are four slide-tape presentations which were developed for use in the wind-tunnel laboratory course.

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ACKNOWLEDGEMENT

I am indebted to Professor R. D. Zucker for his practical and straightforward approach to problems, his enthusiasm for this project, and his interest in the accomplishments of this program. His help and suggestions have been invaluable in the improvement of the lecture program.

I also wish to thank the Educational Media Department of the Naval Postgraduate School for their advice and the use of their materials and equipment in preparing the presentations.

# I. INTRODUCTION

Problems inherent in the teaching of laboratory courses may be alleviated by specially prepared presentations. Several of these problems are presented in detail in a thesis entitled "Tape-Slide Lecture Packages for Use in Aero Laboratories," [Palka 1973]. Some of the problems treated were the overcrowding of laboratory sections, improper briefing of students, the unavoidable absence of student or instructor, and non-standardization of the laboratory sessions.

It was felt that any briefing system proposed must satisfy a number of requirements. It must be adaptable to the Aero labs, suitable for use by any number of students, readily accessible to absentees, and easy to use. The presentations must also be relatively easy to produce and adaptable to future revisions.

Consideration was given to a number of different methods which are currently being used by other schools in the instruction of laboratory courses. Some of these methods are: slide presentations, which are used at the University of Denver [Moe 1972]; a video tape system, which is used in the Mechanical Engineering Department of the University of Nebraska [Dickey 1971]; and the basic audio presentations of audio-tutorial systems, which are used at Boston University and Purdue University [Miller 1973]. The use of instructional television at the University of Nebraska was also reviewed [DeShazer and Edwards 1973]. The slide-tape presentation method was decided upon after considering the other alternatives.

This work is a continuation of a project designed to take the low-speed wind tunnel laboratory course and present its individual weekly experiments as slide-tape lecture packages. Four general information packages have been prepared in the past [Palka 1973]. Two of the four presentations in this Thesis mark the beginning of the actual experiment packages. In addition to briefings for the remaining wind tunnel laboratory experiments, it is felt that other subjects appropriate for presentations are: an introduction to and explanation of wind tunnel boundary corrections, the introductory course to Aero laboratories, and the solid mechanics laboratories.

## II. PURPOSE

One purpose of this thesis was to produce additional presentations to supplement the others already completed in the low-speed wind tunnel laboratory course. It was anticipated that eventually the course could be taught using only slide-tape lecture packages.

Another objective was to see if the student was capable of producing the artwork and doing the photography associated with slide production. Previously this had been done entirely by the Educational Media Department and it was felt that considerable time could be saved if the student did the work himself. If the quality of the presentation did not suffer too much, this method of production could be used within the Aero Department.

A third purpose of this thesis was to determine the effectiveness of this program; the results of this study are presented in a later section.

## III. EQUIPMENT

The presentation of the slipe-tape programs is accomplished by combining a Teaching Dynamics TD-201 audio-visual programmer with a Kodak Carousel remote controlled slide projector. The result, depicted in Figure 1, is a portable, self-contained audio-visual studio, requiring only power and a screen upon which the subject can be viewed.

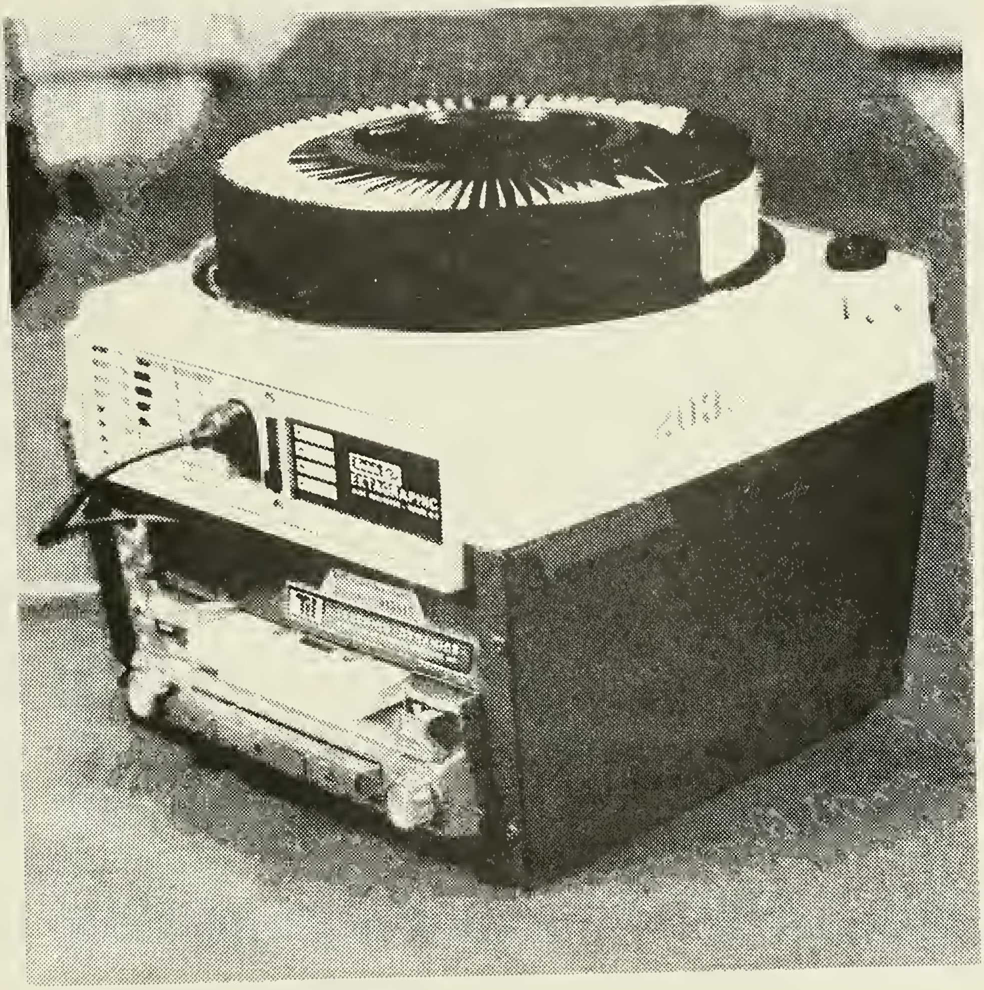

FIGURE 1

The TD-201 uses standard cassette tapes and has complete rewind and fast forward capabilities. The tape has two tracks, of which one is used for recording the audio portion of the presentation and the other for recording the inaudible pulses which automatically advance the slides as the presentation progresses. Other manufacturers make similar pieces of equipment.

# IV. PROCEDURE FOR PROGRAM PREPARATION

The following steps represent a suggested procedure for preparing an automated slide-tape presentation.

## A. INFORMATION SEARCH

A search for information is begun after the subject to be presented is decided upon. As much information as possible is collected both in general background material and in specific material.

## B. OUTLINE

A detailed outline embodying all the important parts of the presentation is produced, studied, and revised.

## C. DEVELOPMENT

The next step involves the preparation of simple sketches on individual production cards, a sample of which is shown in Figure 2. Each of the ideas depicted on separate cards will eventually become a color slide used in the presentation. Brief comments which will aid in final script preparation are also placed on the card at this time. The production cards are then displayed on a planning board as shown in Figure 3 and any changes in presentation order are easily made. The development phase is probably the most important step in producing a good slide-tape presentation.

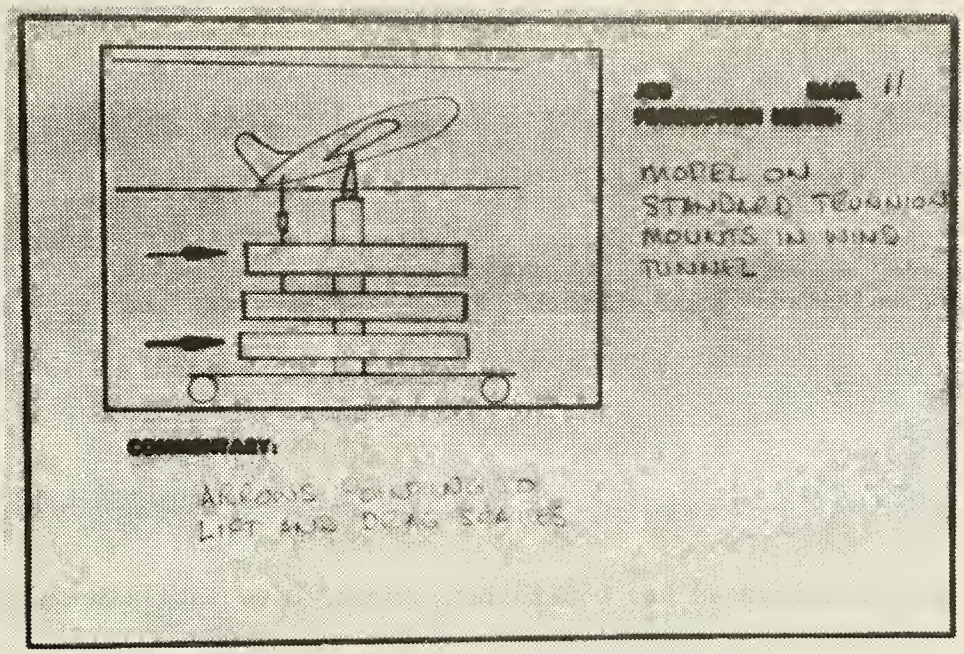


FIGURE 2

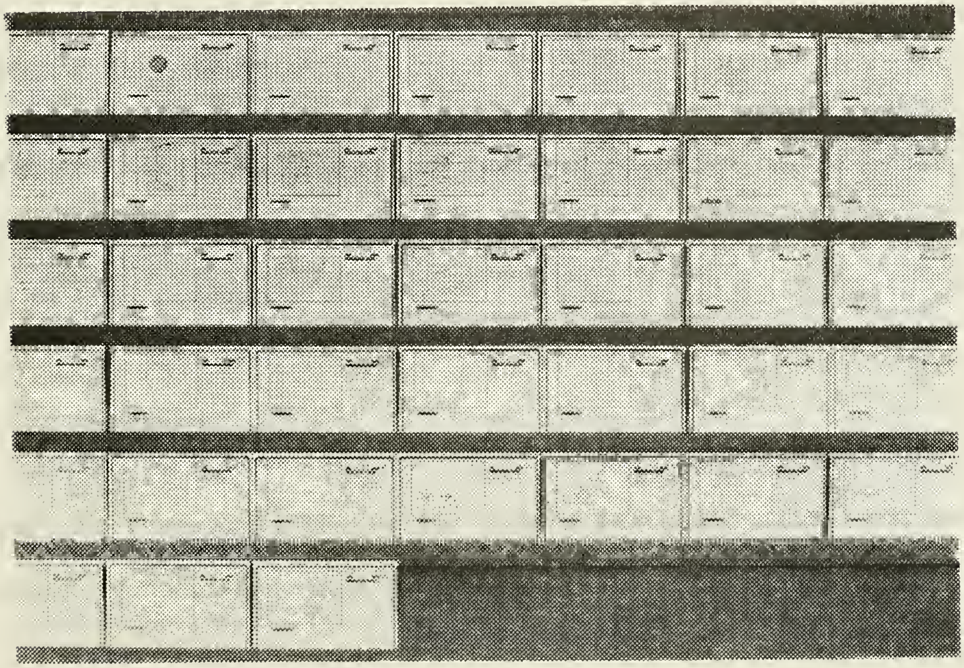

FIGURE 3

## D. SCRIPT WRITTEN

At this point a detailed script is written with special attention paid to the visual concepts displayed on the planning board. The script is then annotated for pulse positions and checked for continuity. When one is very familiar with the subject matter, it is possible to write the script as the ideas are put onto the production cards.

## E. SLIDES PRODUCED

The 35mm slides used in the productions can be produced either by the thesis student or by the Educational Media Department. The steps in production of the slides will be discussed in detail in the section entitled "Slide Production."

## F. PROGRAM REFINEMENT

When the completed slides are reviewed with the script, changes are frequently proposed. Script and/or slides are changed and a smooth keyed script is then prepared.

## G. SOUND RECORDED

Prior to recording, the script should be read orally for practice and the proper pronunciation and pace determined. The sound is then recorded along with the inaudible pulses which automatically change the slides. Music may also be incorporated, usually at the opening and closing of the program.

## H. PRESENTATION REVIEWED AND REFINED

When final revisions have been made, the presentation is stored in the slide-tape library until needed in the appropriate course.

## V. SLIDE PRODUCTION

In an effort to save time it was decided to have the thesis student, rather than the Educational Media Department, produce the slides. The types of slides used and the methods of producing them will be presented here. The equipment available at the Educational Media Department will also be listed along with pertinent information of the use of each piece.

### A. TYPES OF SLIDES

There are two types of slides used in the laboratory presentations, the photo slide and the art slide.

The photo slide is simply what its name implies, a slide of some material that has already been prepared in a publication or some other form that requires no additional drawing or editing. A slide of people operating the equipment used in an experiment or a slide of the equipment itself is considered to be a photo slide in the respect that these slides require no additional graphics work prior to the actual photography.

The art slide is one that requires drawing or editing to be done prior to actually photographing the material. These slides usually require drawing of some kind ranging from humorous cartooning to serious graphics. Lettering is usually also involved and quite often is the most time consuming of the production operations.

## B. PRODUCTION OF PHOTO SLIDES

The production of a photo slide is accomplished by photocopying a portion of some published material or photographing some aspects of an experiment such as equipment, instrumentation, or actual operation of the equipment. When photocopying any portion of a published volume, written permission should be requested and obtained from the publisher of the volume.

The steps used to photocopy a portion of a published work are:

1. If the picture is black and white, make a copy using the 3M "VQC" copier. This will improve the contrast. If the original is in color, it will have to be photographed directly from the volume.

2. Make a mask that reveals only the information required on the page. If the mask does not lie flat, cover it with a piece of glass.

3. Position the camera on the tripod and check positioning through the lens.

4. Adjust the lighting of the subject to the proper positions. It is best to use a polarizing filter to produce maximum lighting with minimum reflection.

5. Focus, set f-stop and shutter speed for proper exposure, and depress the shutter release button.

When photographing equipment or people performing an experiment, the usual rules of photography apply with emphasis placed on lighting conditions which are very important in the use of color film. Light stands and a tripod can be obtained from the Aero Department. A Pentax Spotmatic II camera is also available from the department.

The photo department of EMD is an invaluable source of information and should be consulted whenever a question relating to photography arises. They will furnish any pertinent information pertaining to films.

## C. PRODUCTION OF ART SLIDES

Art slides are generally of two types. One type is usually called the "board" type by graphic specialists and the other is the free form usually characterized by a cartoon or drawing used to clarify some important point in the presentation. A number of equations needed to explain a method or procedure in a specific lab would also be of the second type.

The "board" type of art slide is characterized by a colored background upon which colored letters have been placed for such purposes as titles, subheadings, or progressive disclosure of several lines of information.

The following steps are used in the production of a "board" type of art slide:

1. Use an 8" x 10" piece of cardboard of the desired color for the background.

2. Punch out the required letters on the Leteron machine in the graphics laboratory.

3. Transfer the letters from the Leteron tape to the background using an Exacto knife, paying attention to centering the artwork in a 7½" x 5¼" area on the board.

4. Underlining and accentuation of certain points can be accomplished with the use of Chartpak tapes of different colors.

5. The photographing of the boards is accomplished in the same manner as presented in the photo slide section.

Another method used in producing the "board" type of art slide is given below:

1. Using the headliner, type out the required words and mount them on an 8" x 10" piece of white paper. Attention should again be given to centering the artwork in a $7\frac{1}{2}$" x $5\frac{1}{4}$" area.

2. Make a copy of the paper in the 3M "VQC" copier. This intensifies the printed matter and will produce a better slide.

3a. Using the Heyer-Thermal Processor located in the main graphics office, it is possible to obtain black or white letters on a clear transparency.

3b. Use the Thermo-fax copying machine in the Visual Graphics Lab to produce either a black drawing on a clear transparency or a black drawing on a colored transparency.

4. It is possible to accent certain areas of the artwork by using colored Chartpak tape directly on the transparency.

5. The clear transparency can then be mounted on any colored background and photographed.

The second type of art slide is the free form slide and includes such slides as cartoons, drawings of equipment, and a number of equations. This slide is produced using the same steps listed in the second method above.

## D. USE OF THE EDUCATIONAL MEDIA DEPARTMENT

The Photo Division of EMD will photograph the boards and transparencies for the student or if the photography is to be done by the student, it will

furnish the student film and any information pertaining to photography that is needed.

The Graphics Division of EMD will provide the necessary materials for the student to produce the boards and transparencies needed. The materials and working spaces are located in the Visual Graphics Lab, Room 124D, Herrmann Hall and the room is open from 0800 until 1630 each working day. The student can obtain answers to most of his questions and also instructions on how to operate the machines in the Visual Graphics Lab.

Here is a list of the machines and facilities available for student use. All are located in the Visual Graphics Lab unless otherwise noted.

1. <u>209 Graphics Transparency Machine</u>

This machine reproduces black images on a clear transparency from any black and white original. It can also be used to copy pages out of books onto clear transparencies.

2. <u>Thermo-Fax Copying Machine</u>

This machine is used to make black images on color transparencies from black and white originals. 3M-529 colored transparency paper is used in conjunction with this machine in the production of art slides.

3. <u>Reynolds/Leteron Model LE-200 Tapesign Machine</u>

This machine is used in making adhesive letters for use on boards. The letters are of five different sizes varying from 3/8" to 3/4" high and can be produced in five different colors.

4. Varitype Headliner

This machine is used in making black lettering on a white background for titles, sentences, etc. The letters range in size from 1/16" to 3/4" high. This machine is usually used in the production of the board slide as noted in Section C. This machine is located in the main graphics room.

5. Heyer-Thermal Processor

This machine is used in the production of black or white letters on clear transparencies. It transfers the lettering made on the headliner onto clear transparencies. It is located in the main graphics room.

6. Royal 560 Large Type Typewriter

This typewriter produces a boldface type approximately ¼" high. It can be used when a great deal of typed material is desired on a slide.

7. Varitype Adhesive Wax Coater Machine

This machine puts a wax coating on the back of any piece of paper that is to be mounted on boards. An example would be the use of different colored backgrounds on one board.

# VI. RESULTS

The principal results of this thesis are four slide-tape lecture presentations. The packages are available through the Department of Aeronautics.

## A. PRESSURE DISTRIBUTION OVER AN AIRFOIL - INTRODUCTION

This presentation comprises a 12½-minute audio tape and forty-six 35mm color slides. It introduces the pressure distribution experiment and explains the techniques involved in this type of testing. The keyed script and slide list are contained in Appendix A.

## B. PRESSURE DISTRIBUTION OVER AN AIRFOIL - DATA REDUCTION

This presentation comprises a 15-minute audio tape and forty-three 35mm color slides. It explains the procedures used in reducing the data to useful aerodynamic quantities. The keyed script and slide list are contained in Appendix B.

## C. THE WIND TUNNEL BALANCE

This presentation comprises a 20-minute audio tape and sixty-three 35mm color slides. It introduces the several types of balances, mountings, and linkage systems together with their uses in wind tunnel testing. The keyed script and slide list are contained in Appendix C.

## D. THE AEROLAB "543" WIND TUNNEL BALANCE

This presentation comprises a 15-minute audio tape and fifty-three 35mm color slides. It explains the construction and operation of the wind tunnel balance used in the low-speed wind tunnel at the Naval Postgraduate School. The keyed script and slide list are contained in Appendix D.

## E. EVALUATION OF THE SLIDE-TAPE LECTURE PROGRAM

A questionnaire concerning the slide-tape lectures was given out to the students that had seen the presentations. A copy of the questionnaire is included in Appendix E. The results showed that the students felt that there was a definite need for a program of this type and that prepared handouts were also highly desired. The students felt that presentations which concerned the experiments were more helpful than the general information presentations.

# VII. DISCUSSION

## A. PRESSURE DISTRIBUTION OVER AN AIRFOIL

It was decided during the production of this presentation that it would be split into two sections. The first section discussed the motivation behind the experiment as well as the alternate methods of accomplishing it. This section went on to describe the installation and instrumentation of the equipment and finally the running of the experiment and the required results. The second section of the presentation covered the techniques for reducing the data found in the first section and also included the theoretical development necessary to explain the reduction techniques.

## B. THE WIND TUNNEL BALANCE

This program delves into the various types of wind tunnel balances. It also covers the different kinds of mounting and linkage systems along with the procedures for obtaining tare and interference. Some artwork and photos were copied directly out of [Pope 1954] and [Pope and Harper 1966]. Permission to do this was obtained from the publishers. Although all of the originals were black and white, the slides were of the same quality as the original and adequate for the presentation. This general introduction to wind tunnel balances is very extensive and leads naturally to the discussion of the Naval Postgraduate School's low-speed wind tunnel balance, which is the subject of another presentation.

## C. THE AEROLAB "543" WIND TUNNEL BALANCE

This program is very useful to the student and covers all facets of the balance such as construction, force and moment measurements, linkage systems, and micrometer reading procedures. The handout for this lab can be used by the student during balance operation to insure proper use of the balance and proper reading of the forces and moments.

## VIII. CONCLUSIONS AND RECOMMENDATIONS

### A. CONCLUSIONS

1. The slide-tape presentation is an effective method of briefing for Aeronautical laboratories.

2. The scripts can be easily modified to produce handouts which are very effective when used in conjunction with the individual programs.

3. The individual thesis student is capable of producing a satisfactory quality of artwork needed in the slide-tape productions.

4. Pictures taken by the student are satisfactory if he has a background in photography.

5. The average student is capable of producing the necessary artwork, but the photography should be done by EMD since the requisite level of experience in photography cannot be assured in each student.

### B. RECOMMENDATIONS

1. This project should be continued to include the other experiments in the Aeronautical laboratory courses.

2. Handouts should be prepared for all subsequent labs to complement the slide-tape presentations.

3. A slide-tape library should be established in the Department of Aeronautics and all presentations should be stored there for future use.

4. Unless the student has an appropriate background, the actual photography should be done by EMD.

APPENDIX A

PRESSURE DISTRIBUTION OVER AN AIRFOIL

INTRODUCTION

[9]The analysis of a three-dimensional wing to predict its performance characteristics is a task that frequently confronts the Aeronautical Engineer. [10]One method of approach is to divide the wing into sections and then develop the performance of the entire wing in terms of the information that is available for each airfoil section. Methods for doing this were first developed by Prandtl just prior to 1920 and these have been refined by many others since then. [11]In all of these methods it is essential to know the characteristics of each section. Furthermore, major developments in wing design, such as the supercritical wing, stem directly from investigations on individual two-dimensional sections.

[12]You have used information of this type to solve a number of problems.

[13]Have you ever stopped to wonder how these curves are obtained?...

[14]There are a number of methods that can be used to obtain information on airfoil performance. These are:

Predictions from Potential Flow Theory

Momentum Analysis of the Wake

Direct Measurement of Lift, Drag and Pitching Moments with a Wind Tunnel Balance

Measurement of Pressure Distribution over the Airfoil Surface

[15]You no doubt recall from potential flow theory that sources and sinks can be placed in a uniform stream to generate flow patterns about solid objects. The addition of vorticity generates lift. The appropriate

distribution of these singularities will produce the ideal flow field over an airfoil of a particular shape. [16]Besides being extremely tedious this method has several disadvantages: it will always predict the same ideal lift curve slope, it sheds no light on the stalling characteristics, and it provides no drag information. Thus we shall forsake theory and turn to the testing of a model.

[17]We could measure the velocity distribution in the wake of the model and feed this information into a momentum analysis to determine the drag forces. This is not only a tedious procedure, but more important is the fact that it does not yield information on the lift forces.

[18]Why not mount the model on a balance and directly measure the lift and drag forces as well as the pitching moment? While this is perhaps the simplest and most direct approach, it too, is subject to some drawbacks. Ideally, the foil should extend from wall to wall to provide a true two-dimensional model. However, it can not touch the wall or this would invalidate the balance readings. [19]Thus a gap must exist between the ends of the foil and the tunnel walls. This gap will introduce errors which are difficult to correct. Proper installation can minimize these end effects permitting rapid determination of the total forces and moments; however, no information can be obtained concerning the distribution of these forces.

[20]The final method consists of mounting the foil with no gap between it and the tunnel walls. [21]In the center span, a large number of pressure taps are installed over the upper and lower surfaces of the foil. [22]This permits an accurate picture to be obtained of the actual pressure distribution around the foil. [23]One can then integrate the components of these pressure forces perpendicular to the free stream to obtain the

total lift. Similarly, an integration of the components in line with the approaching velocity will produce the pressure drag. [24]Further manipulation of the data will locate the aerodynamic center and this permits calculation of the moment coefficient about the aerodynamic center. This method involves considerably more work than the direct measurement of the total forces. Another disadvantage is that no information can be obtained on the friction drag which is the major drag that exists up to the point where separation occurs. One might ask, 'why bother to use this method at all?' [25]The answer lies in the additional information provided by the actual pressure distribution. This includes the location of the minimum pressure point and its strength. This is also the point of maximum velocity and will aid in determining the critical Mach number of the section. Knowing the pressure distribution permits calculation of the loads that the skin and structural members must withstand. This would include the maximum pressure and its location. The knowledge of pressure variations is also essential in boundary layer investigations.

[26]This laboratory exercise will be devoted to the testing of an airfoil section by the pressure distribution method. [27]One of the specific objectives is to determine the lift curve of the foil. From this you can determine such important parameters as the slope of the lift curve, and the angle of attack for zero lift. Also, the stalling characteristics are quite evident from the lift curve. [28]Next, you will determine the aerodynamic center. This is defined as an axis about which the pitching moment does not vary with angle of attack. Theoretically, for subsonic flow, the aerodynamic center lies at the quarter chord point; or 25% of the chord length measured from the leading edge back toward the

trailing edge. [29]Once this point has been located, you can then calculate the moment coefficient about the aerodynamic center.

[30]This presentation will describe the installation of the foil in the wind tunnel together with its associated instrumentation. The test procedure will be reviewed, followed by a discussion of the data reduction techniques.

[31]In this experiment you will be using an NACA 66-215 airfoil section. The last two digits of the designator indicate that the airfoil has a maximum thickness which is 15% of the chord length. The model has a chord length of one foot and it is installed between the top and bottom walls of the tunnel. It can be rotated about an axis so that the angle of attack can be varied. [32]The actual adjustment mechanism is installed on top of the tunnel. Be sure to tighten this securely after changing the angle. This is particularly important at high angles of attack.

[33]There are a total of 36 static ports distributed over the top and bottom surfaces of the foil. The even numbered ports are located on the upper surface and the odd numbered taps are on the lower surface. The exact coordinates of each measuring station are given in a separate hand-out. [34]Tubing from these ports pass inside the airfoil and emerge through the axis on the top of the tunnel. [35]Flexible tubing connects each port to the top of a manometer. [36]A common reservoir feeds the entire bank of manometers. [37]One of the manometer tubes is left open to the atmosphere. It is essential to realize that the height of any liquid column is significant. Also, since the tubes are attached to the top of the board, the <u>higher</u> liquid columns indicate <u>lower</u> pressure.

[38]Have a data sheet completely prepared before starting the tunnel. This sheet should not only contain columns for each manometer reading but

also should include an appropriate title together with any additional information taken at the time of the experiment such as the date, atmospheric pressure and temperature, tunnel operating data, etc. Be sure to record the units for all measurements.

[39]Check the micro-manometer to make certain it is properly zeroed. When you are satisfied that everything is in order, start the tunnel and bring it up to speed. [40]Your instructor will indicate an appropriate tunnel velocity for this experiment.

[41]The pressure distribution over the airfoil is vividly portrayed on the manometer board. Remember that the even numbered tubes indicate the pressure distribution over the upper surface and the odd numbered tubes reveal the distribution over the lower surface. Considerable time can be saved by having two people read the manometer board.

[42]When you have completed one run change the angle of attack. Your instructor will designate the various angles to be used for each run. It may be necessary to readjust the tunnel speed after changing the airfoil's position. [43]Notice how the pressure distribution changes as the angle of attack is increased....

[44]Special attention should be directed to the higher angles of attack so as to see the actual stall occur.... [45]....

[46]This concludes the first portion of the briefing. It is recommended that you stop the machine at this point and proceed to carry out the experiment.

PRESSURE DISTRIBUTION OVER AN AIRFOIL

INTRODUCTION

Slide List

1. Blank.
2. Target slide.
3. The Department of Aeronautics Presents.
4. Airfoil at zero degree A.O.A.
5. Airfoil at 10 degree A.O.A.
6. Airfoil at 20 degree A.O.A.
7. Airfoil at 30 degree A.O.A. (separation).
8. Airfoil Performance from Pressure Distribution.
9. Two engineers with three-dimensional model.
10. Wing with individual airfoil sections shown.
11. Engineer looking over data sheets, performance curves, etc.
12. Section lift vs. angle of attack curve for NACA 66-215.
13. Section lift vs. section drag curve for NACA 66-215.
14. Possible methods for obtaining information on airfoil performance.
15. Potential flow featuring source and vorticity.
16. Potential flow wing section shape in airstream.
17. Airfoil section in a wind tunnel with wake velocity distribution.
18. Wind tunnel balance.
19. Airfoil and wall with a gap between them.
20. Airfoil and wall without a gap between them.
21. Airfoil section showing pressure taps along the upper surface.
22. Pressure distribution about an airfoil section.
23. Airfoil section with lift vector.

24. Airfoil section with lift vector, aerodynamic center, and moment about the aerodynamic center.

25. Advantages of Pressure Distribution Analysis.

26. Objectives.

27. Coefficient of lift vs. angle of attack curve.

28. Aerodynamic center.

29. Coefficient of moment about the aerodynamic center.

30. Procedures followed in the experiment.

31. Technician mounting NACA 66-215 in the wind tunnel.

32. Adjustment mechanism for changing angle of attack.

33. NACA 66-215 airfoil section showing pressure taps.

34. Technician connecting tubing from pressure taps on the airfoil to the manometer board.

35. Tubing going to the top of the manometer board.

36. Base of manometer board showing one common lead from reservoir.

37. Schematic diagram showing pressure relationships on the manometer board.

38. Prepared data sheet.

39. Micro-manometer properly zeroed prior to starting the wind tunnel.

40. Setting wind tunnel speed with the micro-manometer and the tunnel controls.

41. Pressure distribution over the airfoil portrayed on manometer board.

42. Technician changing angle of attack.

43. Pressure distribution on manometer board at 6 degrees A.O.A.

44. Pressure distribution on manometer board at 13 degrees A.O.A.--just before separation.

45. Pressure distribution on manometer board at 15 degrees A.O.A.--just after separation.

46. End of Part 1.

APPENDIX B

PRESSURE DISTRIBUTION OVER AN AIRFOIL

DATA REDUCTION

[2]When you have completed the experimental portion of this laboratory, you will have obtained the pressure distribution over the airfoil at various angles of attack. You are now ready to use this information to determine several important section parameters. [3]We shall begin first with the calculation of lift and drag forces.

[4]A coordinate system is established with its origin at the leading edge of the foil. The x-axis extends rearward along the chord line and the y-axis is positive upward. The resultant aerodynamic force can be resolved into two components - cap X and cap Y. These must be obtained by integrating the pressure forces over the surface of the foil. In all calculations we are dealing with a unit span.

[5]To compute the y-component it is convenient to divide the foil into two parts - the upper and lower surfaces. Consider an incremental area on the upper surface. The pressure force on this area is $p_u ds$. The incremental force in the plus y-direction equals - $p_u ds \cos \theta$. But $\cos \theta$ equals dx over ds and thus dY equals - $p_u dx$.

[6]A similar situation exists over the lower surface. Here, the incremental force in the y-direction equals $p_\ell ds \cos \theta$. Substitution for $\cos \theta$ yields $p_\ell dx$....

[7]Summing these quantities makes dY equal to $p_\ell dx - p_u dx$ and integration from the leading to trailing edge will produce the total y-component.

[8]The pressure at infinity may be added to and subtracted from the integrand without affecting the value of the integral. If we divide both sides by the free stream dynamic pressure times the chord, some familiar quantities result.

[9]The quantities under the integral are pressure coefficients and on the left side of the equation we have a force coefficient. [10]Thus, the equation can be written in the nondimensional form shown. A simple change of variable with a corresponding change in the limits of integration completes the picture.

[11]The evaluation of this integral is done by numerical or graphical methods. After calculating the pressure coefficients one plots $C_{p_\ell} - C_{p_u}$ vs. x/C. The area under the curve can be obtained by use of Simpson's rule.

[12]An alternate method is to measure the area with a planimeter. This is probably the most accurate method available for finding the area under the curves that you will be generating in this lab.

[13]The x-component of the pressure force is found in a similar manner, only this time it is more convenient to divide the foil into forward and rearward portions. For the forward portion dX equals $p_f ds \sin\theta$. Substitution for $\sin\theta$ gives $p_f dy$ for the incremental force in the x-direction.

[14]An incremental area on the rear portion of the foil presents a similar picture. Here, the relations are identical except for the inclusion of a negative sign and dX is seen to equal $- p_r dy$....

[15]These two components are summed and then integrated from the lower extreme $-y_1$ to the upper limit of $+y_2$....

[16]We again introduce $p_\infty$ into the integrand and divide both sides by $q_\infty c$. The result is a nondimensional equation for the force coefficient $C_X$. This integral can also be evaluated graphically.

[17]We must now relate the x and y force components to the lift force which is defined as being perpendicular to the free stream. From the diagram it can be seen that the lift force equals Y cos $\alpha$ - X sin $\alpha$. These can be eaily put into a non-dimensional form with the various force coefficients shown.

[18]At this point we might discuss the assumptions made for may airfoils. First, that the foil is thin; second, that it has small camber; and third, that it operates at low angles of attack.

[19]If these conditions exist, the usual small angle approximations can be made. Furthermore, examination of the pressure distribution reveals that $C_X$ will normally be much less than $C_Y$.

[20]Making the small angle substitutions, we have lift coefficient approximately equal to $C_Y$ minus $\alpha C_X$. Note that the last term is a product of two small quantities and in most cases is neglected.

[21]We now turn to the evaluation of the drag force, or that component in line with the free stream. From the picture we see that the drag equals X cos $\alpha$ + Y sin $\alpha$. The corresponding expression is also shown in a non-dimensional form. [22]If we make the usual small angle substitutions, we have the drag coefficient approximately equal to $C_X$ plus $\alpha C_Y$.

[23]To summarize, we have obtained the force coefficients in the y and x directions by graphical integration of the pressure coefficients. [24]From these we obtained the lift coefficient and the drag coefficient. [25]Within the limitations of thin airfoil theory these may be approximated as shown. Note that the entire equation for the drag coefficient is an order of magnitude less than that for the lift coefficient. We also know from ideal flow theory that unless separation has occurred, the pressure drag should be zero.

[26]After computing the lift coefficient for each test we can plot the lift curve $C_\ell$ vs. $\alpha$. From this curve important parameters such as the slope of the lift curve and the angle of zero lift can be determined. Also, the stalling characteristics are readily observed.

[27]We now turn to the calculation of the pitching moment. [28]We define a positive moment as one which tends to pitch the nose upward. Consider an incremental area located at coordinates x and y, whose force components are as shown. The differential moment about the leading edge equals ydX minus xdY. [29]We substitute the expressions previously obtained for the differential forces and integrate these over the entire foil surface to obtain the total moment.

[30]If we divide the entire equation by $q_\infty c^2$ we can reduce it to a dimensionless form by defining the moment coefficient about the leading edge; and we then obtain the rather formidable looking integral expression shown.

[31]For extremely thin foils with little or no camber, the first integral is frequently smaller than the second, and one can approximate the moment coefficient with only the latter term as shown. Only through experience can one tell when this simplification is permissible.

[32]We proceed now to investigate the aerodynamic center, which can be located in the following manner. [33]We have represented the pressure forces by equivalent x and y components together with a moment. There is nothing unique about the location of this force system; it can be moved to any point on the foil providing the moment is correctly adjusted. Let us move the force system to the aerodynamic center. Let $x_{ac}$ equal the distance from the leading edge back to the aerodynamic center. Then the moment about the aerodynamic center equals the moment about the leading edge plus $Y(x_{ac})$.

[34]Consider now what happens as the angle of attack changes by a small amount. A small change occurs in the Y force and also in the moment about the leading edge. However, by definition, the moment about the aerodynamic center does not vary with angle of attack. The resulting expression is easily solved for $x_{ac}$. [35]In the limit, for infinitesimal changes in angle of attack, the ratio on the right side becomes a derivative. This expression can then be put in a nondimensional form in terms of the moment and force coefficients. This equation shows that a knowledge of the variation of $C_{m_{L.E.}}$ and $C_Y$ enables one to determine the location of the aerodynamic center.

[36]Plot these parameters, and the negative of the slope represents the distance $x_{ac}$ as a fraction of the chord. The curve will be linear for small angles of attack but will become nonlinear as the boundary layer begins to separate. Once the aerodynamic center has been located, it is a simple matter to calculate the moment about this point.

[37]In summary - we have indicated several ways of determining the performance of airfoils and have discussed some advantages and disadvantages of each. We have described the installation and test procedures connected with the pressure distribution method. Equations were developed which showed how the data must be reduced to provide the desired performance parameters. The most important parameters are the slope of the lift curve, the zero lift angle of attack, the stalling characteristics, the location of the aerodynamic center, and the moment coefficient about the aerodynamic center. Once this information has been determined it should be compared to published data that is available for similar airfoils. You will be informed by your instructor as to the assumptions and simplifications that should be made in the data reduction. He will also give guidance concerning what is desired in the form of a final report.

PRESSURE DISTRIBUTION OVER AN AIRFOIL

DATA REDUCTION

Slide List

1. Blank.
2. Data Reduction for Airfoil Performance.
3. Data Reduction--lift and drag forces.
4. Airfoil with differential upper pressure force and Y force.
5. Differential upper pressure force broken up into components.
6. Differential lower pressure force broken up into components.
7. Differential component dY equation and total force Y integral equation.
8. Pressure at infinity is introduced into the Y equation and both sides are divided by the free stream dynamic pressure.
9. Resultant pressure coefficient and force coefficient.
10. Non-dimensional force coefficient and limit change.
11. Graph of pressure coefficient difference vs. position.
12. Engineer using a planimeter to evaluate the integral.
13. Differential forward component of the pressure force in the X direction.
14. Differential rearward component of the pressure force in the X direction.
15. Integration of the differential X force components.
16. Non-dimensional X force coefficient.
17. Relationship of X and Y forces to the lift force.
18. Thin Airfoil Assumptions.
19. Small angle approximations.
20. Lift coefficient equations.
21. Evaluation of the drag force.

22. Drag coefficient equations.

23. X and Y force coefficient equations.

24. Lift and drag coefficient equations.

25. Lift and drag coefficient approximations under small angle assumptions.

26. Lift curve.

27. Data Reduction--pitching moment.

28. Definition of positive moment and differential moment.

29. Differential moment and moment integral equations.

30. Dimensionless moment coefficient equation.

31. Moment coefficient for extremely thin airfoils.

32. Data Reduction--aerodynamic center.

33. Representation of pressure forces by X and Y components with a moment.

34. Equations for a change in the moment about the aerodynamic center and the position of the aerodynamic center.

35. Equation of position of the aerodynamic center and the aerodynamic center position divided by the chord.

36. Graph of the coefficient of moment about the leading edge vs. the coefficient of the force Y.

37. Summary.

38. Airfoil at high A.O.A.

39. Airfoil at lower A.O.A.

40. Airfoil at lower A.O.A.

41. Airfoil at zero A.O.A.

42. A Wallace-Zorro Production.

43. Blank

## APPENDIX C

## THE WIND TUNNEL BALANCE

It is difficult to accurately estimate some of the performance and stability parameters of an aircraft or missile by purely analytical methods. In order to determine these important parameters more precisely one must eventually build a model and conduct tests in a wind tunnel. After making the appropriate tunnel corrections the data can be scaled up to predict the performance of the full size prototype with reasonable accuracy.

The success of such a procedure depends on the knowledge of the following aerodynamic forces and moments acting on the vehicle: [6] the lift force, which is the component of force perpendicular to the undisturbed airstream, [7] the drag force, which is the component of force acting in the same direction as the undisturbed airstream, [8] and the side force, which is the component of force mutually perpendicular to the lift and drag. These three forces form a coordinate system which is usually referred to as "wind axes."

The moments are normally measured with respect to a different set of axes which are fixed in the vehicle, and called "body axes."

[9] The X-axis points forward along the fuselage centerline. Moments about this axis are called rolling moments and are positive when tending to force the right wingtip down.

[10] The Z-axis is perpendicular to the X-axis and points downward in the plane of symmetry. Yawing moments are about this axis and are considered positive if they tend to push the vehicles nose to the right.

[11]The Y-axis is perpendicular to the XZ plane and extends in the positive direction out the right wing. The pitching moment acts about this axis and is positive when it tends to increase the angle of incidence or pitch the nose of the vehicle upward.

There are three methods that can be used to obtain these forces and moments:

[12]A survey of the wake combined with the pressure variation along the tunnel walls can be used to determine the effect that the model has on the airstream.

[13]The actual pressure distribution over the model can be determined by pressure gages connected to numerous orifices on the model. Unfortunately, this method will not reflect the frictional forces. Both the wake survey and the pressure distribution method require tedious data reduction procedures.

[14]The simplest method is the direct measurement of forces and moments by the use of a wind tunnel balance. Although this is the easiest method, it is also the most expensive. A simple balance for use in a 7 x 10 foot, 150 mph tunnel can cost $30,000 and the complex apparatus required in larger tunnels can run $200,000 or more. Another consideration is the fact that the balance must be accurately aligned and calibrated.

There are basically two general classes of wind tunnel balances, internal and external. [15]An internal balance is mounted inside the model and the entire assembly is usually mounted on a sting as shown. [16]The internal balance is in two parts, one plate is attached to the model and the other plate is attached to the mounting. These two parts are connected by flexures whose movement is measured by strain gages.

[17]The remainder of this presentation will be concerned with external balances. We shall discuss the main features of the external balance, the calibration of the balance, and a method for determining the interference and tare measurements. [18]The main features used for classfying external balances are:

the type of mounting employed

the kind of linkage system used to transmit the forces and moments

and the type of measuring unit used.

[19]A typical mounting is shown in this slide for the purpose of discussing some nomenclature. The main supports are called "struts." Note that the front strut is designed for rigidity to carry the load and thus is large and not well streamlined.

The "windshield" is an aerodynamically designed shield which covers the lower portion of this strut.

The "bayonet" is an extension of the main strut outside the windshield. This portion of the strut is much smaller and well streamlined for minimum drag.

The trunnion is the point at which the strut's bayonet is attached to the model.

[20]When the model is mounted in the wind tunnel it is important to note that any strut or wire connecting the model to the balance will effect the measurements in two basic ways.

The drag of the strut or wire is the first and most obvious quantity which is called the "tare." Next is the effect of the strut's presence on the free air flow around the model. Also, the presence of the model effects the free air flow around the strut. The last two terms are usually combined under the heading "interference."

At present there are numerous methods employed to mount models in a wind tunnel. Several of these methods will be illustrated and briefly discussed.

[21]The single strut mounting is the first method. This arrangement is the simplest and if the model is small this method is very useful. However, the model size is usually so large that the single strut is not rigid enough, especially in torsion.

[22]An increase in the resistance to roll deflections is gained through the use of a fork with a single strut but the torsional rigidity is not appreciably increased. Extra interference is also added with the presence of the fork.

[23]A two-strut system is more rigid than the single strut system; however, this adds the complication that the windshields must be removed and rotated in order to yaw the model for testing purposes.

[24]The conditions of rigidity, tare and interference evaluation, and the ease of varying the angle of attack are all met in the three-point mounting method. The complication of this method is that when the model is yawed sideforces are introduced by the rear strut and these complicate the yawing moment measurements.

[25]Wingtip mounting leaves the fuselage and nacelles unobstructed by supports and surrounded only by air. This method is primarily used when it becomes necessary to determine the pressure distribution of regions close to the struts.

[26]Extremely large models are tested by splitting them down the plane of symmetry. Asymmetric flow is prevented by placing a large plate at the plane of symmetry. This system yields accurate pitch, lift, and downwash data.

[27]The need for wing struts is done away with by mounting the model on a cantilever tail sting. The model drag appears to be less with this type of mounting due to the wake stabilization by the tail sting.

[28]The linkage systems for external wind tunnel balances are separated into four types, each of which is named from its main load-carrying members. They are wire, platform, yoke, and pyramidal.

[29]Wires support the model in a wire balance and these wires are connected to simple beam balances which measure the load on each wire. An elementary wire balance is seen here. Individual operators use weights to bring the balances to equilibrium and the forces are then read.

[30]The results from this particular model can be seen to be combinations of the readings taken. Although this is a disadvantage of most balances, we will see a balance later where the forces and moments can be read directly. Even though a wire balance is the simplest and the easiest to build, it has several disadvantages. The wire balance has an inherently large tare drag due to the initial tension required in all of the wires. This large tare cannot be accurately determined. Also, the wires in a wire balance have a tendency to corrode and break which is a serious disadvantage as the model itself could be broken or entirely destroyed.

[31]Three or four legs are used to support the platform balances main frame as seen here. Platform balances are widely used because they are rugged and orthogonal, which means they can be aligned without much difficulty. [32]One of the major disadvantages of the platform balance is that all six components cannot be read directly but must be obtained by summation. It is particularly difficult to obtain accurate rolling and yawing moments as these appear as small differences between large forces. Furthermore, the pitching moments must be transferred up to the

airplanes axes due to the fact that the resolving center is at the bottom of the mount.

[33]This latter problem is solved with the yoke balance, in which the moments are read about the model. This is accomplished by having the balance frame span the test section so that the pitch axis can pass through the model. This not only requires high supports but also introduces a long yaw lever arm. The disadvantage of this design is that it experiences larger deflections than the platform balance.

[34]The force and moment components found with a yoke balance are also combinations of measurements and cannot be read directly....

[35]The asymmetric configuration of the yoke balance as seen here reduces the length of the yaw and roll lever arms by as much as 50% and divides the moment forces accordingly.

[36]The pyramidal balance largely overcomes the disadvantages of the platform and yoke balances. Here we see a basic pyramidal truss system. It can be shown that moments about the apex will cause a restoring force shown as Cap A. However, forces such as D, which act through the apex, will not affect the magnitude of Cap A. Thus, the moments can be singled out in a simple manner which does not require differences between two readings.

[37]In actual practice, the legs of the pyramid are cut off so as not to interfere with the airstream. The extension of each leg must pass through the resolving center which points out the major disadvantage of the pyramidal balance. Its construction and alignment are extremely critical. Calibration is also critical as any deflection of the inclined struts or legs will introduce errors in the moment readings.

[38]The advantages of the pyramidal balance far outweigh the disadvantages. Not only are moments read about the resolving center but all six force and moment components can be read directly....

[39]Whatever the balance type and whatever the mounting method employed, the calibration of the balance must be checked to ascertain that the forces are properly separated and the elements are mutually perpendicular.

[40]With the calibration rig shown, the various loads and moments can be applied separately, and the independence of the readings, as well as the accuracy, can be determined. For example, no drag should be produced in the system by the addition of weights at A, B, or C.... Also a weight moved to F from E should produce no change in drag....

The weights should be progessively added to one component and all six components should be read. By doing this, the effect of each force on each of the other components can be measured. The process should be repeated with all the components, and corrections and adjustments made until the accuracy and calibration are known.

[41]Another essential part of preparing a wind tunnel balance is alignment. To properly align the wind tunnel balance with the airstream, it is necessary to have the drag scales read pure drag without including any component of lift. In other words, the lift must be perpendicular to the airstream and the drag parallel with it.

[42]Alignment is simplified by knowing that the lift for most tests is 5 to 25 times larger than the drag and it is usually sufficient to align the balance so that the drag-reading apparatus will not contain any lift in its readings. It is generally not necessary to see whether the lift-reading apparatus contains any drag in its readings. One need only ascertain that the drag system is perpendicular to the lift.

[43]The model supports in a wind tunnel setup will have some drag themselves and will effect the free air flow around the model. The effect on the free air flow around the model is called "interference" and the drag of the supports is called "tare"....

[44]Removing the model and measuring the forces on the supports would seem the easiest method to determine the tare, but this procedure exposes parts of the model support not ordinarily in the airstream. It also fails to record the effect of the model on the supports or the effect of the supports on the model. Thus, the evaluation of the interference and tare is a complex procedure. For most problems it is usually sufficient to determine only the sum of the interference and tare; but in the interest of clarity we shall describe a procedure to evaluate them separately.

[45]The first step is the normal testing of the model with the tare and interference contained in the data taken. The drag that is measured has three components:

[46]the drag of the model in the normal position;

[47]the drag of the supports on the lower surface;

[48]and the interference between the supports and the lower surface.

[49]The second step includes using an image system to support the model from the tunnel roof. The normal supports from the tunnel floor extend into, but do not touch the model, as a small clearance is provided for them.

[50]The balance in this configuration reads the drag of the exposed portions of the supports in the presence of the model. The drag measured is only the drag of the lower supports, or the tare.

[51]For finding the interference the model is inverted and supported with the supports from the tunnel floor and run with the upper image supports just clearing their attachment points.

[52]The drag measured in this case has four components: [53]the drag of the model inverted; [54]the drag of the supports on the upper surface; [55]the interference between the supports and the upper surface; [56]and the interference between the supports and the lower surface....

[57]The image system is then removed and a second run is made with the model inverted....

[58]The drag read in this run has three components: the drag of the model inverted; the drag of the supports on the upper surface; and the interference between the supports and the upper surface....

[59]The difference between the drag measured on the two inverted runs can be seen to be the interference between the supports and the lower surface....

[60]In this presentation we have looked at the wind tunnel balance in a general fashion and have seen what information can be found using the balance. We saw that the balance is the easiest method of finding the forces and moments on a model under load conditions in a wind tunnel. [61]The two general catagories of balances were explored, the internal only slightly but the external quite thoroughly. The main features of external balances were then discussed, starting with the various methods of mounting models. The common types of linkage systems were described and the advantages and disadvantages of each were noted. [62]Calibration and alignment procedures were then discussed. Finally, the determination of interference and tare measurements was illustrated....

This concludes the general introduction to wind tunnel balances. You are now ready to study the details of our particular balance, which is the subject of another presentation.

THE WIND TUNNEL BALANCE

INTRODUCTION

Slide List

1. Blank.
2. Target slide.
3. The Department of Aeronautics Presents.
4. The Wind Tunnel Balance.
5. Model mounted on wind tunnel balance.
6. Lift force on an aircraft.
7. Drag force on an aircraft.
8. Side force on an aircraft.
9. Rolling moment on an aircraft.
10. Yawing moment on an aircraft.
11. Pitching moment on an aircraft.
12. Airfoil in a wind tunnel with associated wake velocity distribution.
13. Model with pressure tap distribution.
14. Model in a tunnel on a wind tunnel balance.
15. Internal balance inside model on sting mount.
16. Parts of the internal balance.
17. External balances-main features, calibration, and interference and tare.
18. Main features of external balances.
19. Typical mounting with associated nomenclature.
20. Effects of mounting.
21. Single strut mounting.
22. Fork type mounting.

23. Two-strut mounting.

24. Three-point mounting.

25. Wingtip mounting.

26. Split model.

27. Tail-sting mounting.

28. Types of linkage systems.

29. Wire balance.

30. Wire balance with force and moment calculations.

31. Platform balance.

32. Platform balance with force and moment calculations.

33. Yoke balance.

34. Yoke balance with force and moment calculations.

35. Asymmetrical yoke balance.

36. Pyramidal balance truss system.

37. Pyramidal balance.

38. Pyramidal balance with force and moment calculations.

39. Reasons for calibration.

40. Calibration rig.

41. Lift and drag alignment.

42. Relative magnitudes of lift and drag.

43. Interference and tare.

44. Model removed from the test supports.

45. Equation for the drag measured in the normal testing of the model.

46. Same as above with the drag of the model in the normal position added.

47. Same as above with the drag of the supports on the lower surface added.

48. Same as above with the interference between the supports and the lower surface added.

49. Image system supporting model from tunnel roof.

50. Drag measured is the drag of supports on the lower surface.

51. Diagram of inverted model with image supports clearing support points.

52. Equation for the drag measured in the inverted run.

53. Same as above with the drag of the model inverted added.

54. Same as above with the drag of the supports on the lower surface added.

55. Same as above with the interference between the supports and the upper surface added.

56. Same as above with the interference between the supports and the lower surface added.

57. Diagram of the inverted run without the image system.

58. Equation for the drag measured in the inverted run with the image system removed.

59. Difference in the equations for run 1 and run 2 is the interference of the supports on the lower surface.

60. Summary of balance showing information obtained from the balance and that the balance is the easiest method of measuring the forces and moments in a wind tunnel.

61. Same as above with the two general catagories of balances, mounting methods and descriptions of linkage systems added.

62. Same as above with calibration and alignment and tare and interference added.

63. A Wallace-Zorro Production.

## APPENDIX D

## THE AEROLAB "543" WIND TUNNEL BALANCE

[5]The Aerolab "543" Wind Tunnel Balance is a combination of three separate force measuring systems. Two of these measure directly the lift, and either the drag or side force. The third is connected in such a manner as to indicate either the pitching, rolling, or yawing moment.

[6]For normal usage the balance is arranged to indicate lift and drag forces along with pitching moment. For this configuration the model is supported on the balance by two wing struts which restrain the model against lift, drag, and yawing moment, and a tail or nose strut which restrains the model from pitching about the wing trunnion attachment points.

[7]It is difficult to look at the balance and tell exactly how the forces are transmitted to the appropriate measuring beams. We shall attempt to show this in the following schematics.

[8]The balance is composed of three basic parts. A 3" diameter column is positioned vertically in the center. The wing struts which support the model are rigidly attached to the top of this column.

[9]Surrounding this central column is a tubular framework which is called the drag cage....

[10]Beneath the drag cage is a platform. The platform is mounted on wheels permitting the entire balance to be easily moved.

[11]These three components are connected by a specially designed system of small diameter linkage rods which restrain all motion and permit forces to be transmitted between the components in certain directions only.

[12]Remember that the model is mounted on top of the central column. In most models pitching moments are transmitted through a tail strut. In others, it may be more appropriate to use a nose strut (as is shown for this model). Both the fulcrum for the pitch linkage and the pitch measuring scale are mounted on the central column.

[13]The measuring scale for the lift force is mounted on the drag cage. The only vertical support for the central column is the rod between the column and the measuring scale. Thus this scale will reflect a true indication of the lift force.

[14]Horizontal forces can be transmitted between the central column and the drag cage through the connecting rods shown. The force is then transmitted through another rod to the measuring scale which is attached to the platform....

[15]Note that the small rods between the drag cage and the platform support the weight of the entire balance but do not interfere with the measurement of the drag force.

[16]Similarly, if the horizontal rods between the central column and the drag cage are properly aligned they do not affect the previously described lift force mechanism. These rods, or flexure pivots as they are sometimes called, are easily replaced if accidental overload or damage should occur.

[17]We have described the normal configuration of the balance as it is used to measure lift, drag and pitching moment. By using other arrangements it is possible to read various combinations of component groups.

[18]To measure the yawing moment, the moment beam is disconnected from the pitching moment system and the pitch system is locked to restrain the model in pitch. The yaw restraint rod is then removed and the moment beam is connected to a new flexure rod which restrains the rotation of the central column.

[19]When measuring yawing moment the model may be mounted on standard trunnion mounts. However, for large amounts of yaw the model should be mounted on a single round strut. With this configuration the moment beam will indicate the yawing moment about the axis of the central column. The actual value of the yawing moment is one-tenth of the value indicated on the moment beam.

[20]To measure side force it is necessary to rotate the entire balance 90 degrees and remount the model.

[21]In this configuration the struts must be realigned with the airflow and new trunnion mounts provided in the fuselage of the model. With the balance oriented in this fashion the balance system that previously indicated drag now measures the side force.

[22]In this view of the same configuration we see that the moment system is connected to one of the wings and with its normal hook-up would indicate the rolling moment. As before, the appropriate changes can easily be made so that the moment balance would indicate the yawing moment.

[23]Thus we see that although the balance has only three measuring systems, all six components can be found in one of the following set-ups. With the balance in one position, lift, drag and either pitching or yawing moment can be measured. With the balance rotated 90 degrees, lift, side force and either rolling or yawing moment can be determined.

[24]The balance linkage and measuring systems have been designed for certain maximum loads. For safe operation the lift force should not exceed 150 lbs. Drag and side forces are limited to 50 lbs. Pitching and rolling moments may go to 1000 inch-pounds but the yawing moment should not exceed 100 inch-pounds.

25 The lift measuring system is sensitive to one-hundredth of a pound. The system which measures drag or side force is sensitive to five-thousandths of a pound. Sensitivity of the moment system is five-hundredths inch pounds.

26 The balance must be carefully installed to obtain proper results. It should be leveled using the central column as a reference. The drag axis should be parallel to the test section centerline.

27 Care should be taken when mounting the model to insure that the support struts clear the test section floor cutouts by approximately ¼ inch. It is imperative that nothing contacts any part of the balance or model supports or the readings will be invalid.

28 The pitch or yaw angle vernier dial should be zeroed after the model has been aligned with respect to the test-section centerline.

29 It is desirable to counterbalance the effects of the model weight so that the initial or tare readings on all scales will be zero. To do this we first set all scales on zero. This includes not only the large and small slides but the rotary weights as well.

30 The weight of the model can now be balanced out using the sliding weights located at the <u>back</u> of the beam for rough adjustments and the rotary weights located <u>between</u> the beams for fine adjustments. More weight may be added if these are insufficient.

31 It is easy to tell when a force or moment system is in balance as this will be indicated by a uniform flickering of the two neon lights on the end of the measuring scale. These lights are actuated by sensitive contact points which should be adjusted to a clearance of 3 to 6 thousandths of an inch. The instruction manual contains information on adjusting this clearance should it be necessary to do so.

[32]These neon lights require 110 volt AC current and a toggle switch is located near the power receptacle so the lights may be turned off without disconnecting power from the balance.

[33]Any balance beam has a tendency to oscillate as it approaches the balanced condition. These oscillations are minimized by the use of vibration dampers, or dashpots, which are located near the end of each measuring beam. The dashpots are adjustable and the desired valve position can be determined quickly by trial and error.

[34]Pitching the model will shift its center of gravity, and this will effect the moment beam zero position. Tare readings should be taken at various angles of attack to produce a curve similar to that shown. You will need these tare readings for later data reduction.

[35]Each force and moment measuring system is entirely independent and may be balanced singly or in any combination.

[36]The model forces are balanced by manually moving weights, with large changes being made by moving these weights along the graduated notched beams.

[37]When moving weights to balance a beam, care should be taken to lift the weight and move it to the new position. Do not slide it along the beam.

[38]Make certain that each weight is properly seated in the notches. It should not be cocked as shown in this picture.

[39]Small adjustments are obtained by rotating the weight on the graduated threaded spindle.

[40]The beams are graduated for both positive and negative loads. A mark taped on the beam indicates which end is positive and which is negative.

[41]Note that the large sliding weight has only one central or zero position, but that the small sliding weight and the rotary weight have two zero positions, which separate the positive and negative scales.

[42]When the forces being measured pass through zero, the small sliding weight is moved over one notch to the other zero, and the rotary weight is also moved to its other zero.

[43]To help you keep these zero's straight, the righthand range on all of the three beams is associated with green arrows painted on the sliding weights. When in this range, use the green scale for the rotary weight. The left-hand range is painted red and when on this side use the red scale on the rotary weight. This procedure will insure that the value read from the rotary scale is always additive to those of the sliding weights.

[44]The following slides will provide an example in reading the balance beam values.

[45]Notice that both slides are on the right side of the moment beam. The tape mark at the end of the beam shows that we are measuring a negative moment. Always keep both sliding weights on the same side of the beam as this will give additive readings.

[46]Since the slides are on the right side of the beam we read on the right side of the slides. 400 is indicated by the large slide and 40 by the small one. Together they represent 440 inch-pounds. Note that the readings are indicated by the first numbers that you can read on the beam. From the arrow on top of the slides we are reminded that we are to use the green scale on the rotary weight.

[47]Here is a close up of the rotary weight. Using the scale indicated by the green arrow we can easily read the first digit as a 2. Each unit on the spindle is split into four equal parts and each part is further

divided into 25 increments. In this example the rotary weight is past two of the four increments between 2 and 3 on the spindle and hence the reading is someplace between 2.50 and 2.75.

[48]One turn of the rotary scale equals 25 increments. The increments showing the example are 12 and these are added to the 2.50 to give 2.62 inch-pounds as the readings indicated by the rotary weight.

[49]Adding all the readings together yields a final reading of 442.62 inch-pounds. Lift and drag balance beams are read in the same manner but indicate forces to the thousandths of a pound.

[50]Here is an example on the drag scale. The weights are on the left or positive side and indicate 33 pounds.

[51]Since the slides were on the left side we must read the rotary weight from the red scale. In this case, .307 is indicated which gives a final positive drag reading of 33.307 pounds.

[52]We have described the operation of the three linkage systems and discussed the various configurations that are possible with this balance. Procedures used to compensate for model weight and obtain tare readings were also discussed. Balancing procedures were covered and examples of both types of scale readings were explained.

[53]This completes your introduction to the Aerolab "543" Wind Tunnel balance. When you go out into the lab you should attempt to identify the various balance parts and verify its operation. Any questions should be taken up with the lab technician or your instructor.

THE AEROLAB "543" WIND TUNNEL BALANCE

Slide List

1. Blank.
2. Target slide.
3. The Department of Aeronautics Presents.
4. The Aerolab "543" Wind Tunnel Balance.
5. Title slide showing two different measuring systems, the one moment and the two forces.
6. Photo of model on balance showing struts.
7. Photo of balance from a position above it to show the intricate construction.
8. Diagram of model supported on the balance's central column by the wing struts.
9. Same as above with the drag cage added.
10. Same as above with the platform added.
11. Same as above with the linkage rods added.
12. Diagram of the pitch measuring system.
13. Diagram of the lift measuring system.
14. Diagram of the drag measuring system.
15. Photo of the small vertical rods between the drag cage and the platform.
16. Close-up of the horizontal linkage rod connection to the drag cage.
17. Title slide of alternate balance configurations.
18. Title slide showing lift, drag, and yawing moment.
19. Photo of the model mounted on a single strut for yaw measurement.
20. Title slide of side force.
21. Drawing of the balance rotated 90 degrees and the model remounted to measure side force.

22. Drawing of the same configuration with the moment system hooked up to measure rolling moment.

23. Title slide showing the various set-ups that are available with the balance.

24. Slide showing the load limitations of the balance.

25. Slide showing the sensitivity of the various measurements made on the balance.

26. Photo showing the balance being levelled using the central column as a reference.

27. Photo showing that the support struts clear the test section floor cutouts by at least ¼ inch.

28. Photo of pitch and yaw vernier dial.

29. Photo of all the scales at the zero values prior to balancing out the weight of the model.

30. Photo of sliding weights and the vernier in back used to zero out the weight of the model prior to testing.

31. Photo of neon signal lights.

32. Photo of toggle switch on the balance used to control the power to the lights.

33. Photo of the dashpots used to damp out the vibrations of the scales.

34. Photo of curve of tare readings versus angle of attack for the balance.

35. Title slide showing balancing procedures.

36. Photo of large and small sliding weights on one of the beams.

37. Photo of someone lifting a weight off one of the beams.

38. Photo of a slide that is cocked on one of the beams.

39. Close-up photo of the rotary weight on the graduated spindle.

40. Photo of beam showing positive and negative marks taped to the beams.

41. Photo of the sliding weights and rotary weights set at zero positions.

42. Same photo as above with a right hand zero shown on each scale.

43. Photo showing red and green colors on sliding weights and rotary weights.

44. Title slide showing example of scale reading.

45. Photo of sliding weights on right side of the beam.

46. Photo showing sliding weights indicating a moment of 440 inch-pounds.

47. Photo of rotary moment weight showing a green reading of 2.62 inch-pounds.

48. Photo of rotary weight showing close-up of reading.

49. Title slide showing the addition of the readings of the three weights.

50. Photo of drag sliding weights reading 33 pounds.

51. Photo of drag rotary weight showing a red reading of .307 pounds.

52. Title slide showing a summary of the presentation.

53. A Wallace-Zorro Production.

## APPENDIX E

## QUESTIONNAIRE ON SLIDE-TAPE BRIEFINGS

The slide-tape programs that were shown during the 3851 laboratories are the result of an ongoing thesis project. Considerable time and effort has gone into the preparation of these programs and it is our desire to assess their worth. Your cooperation in completing this questionnaire as soon as possible will be appreciated. Thank you.

1. Check the presentations that you saw.

   ☐ A. Introduction to Low Speed Wind Tunnels (History, classification, etc.)

   ☐ B. The Aerolab Low Speed Wind Tunnel (Details of NPS tunnel)

   ☐ C. Operating Instructions for the Aerolab Tunnel

   ☐ D. Airfoil Performance by Pressure Distribution - Part I (Introduction)

   ☐ E. Airfoil Performance by Pressure Distribution - Part II (Data Reduction)

2. Do you feel that there is a need for presentations of this type?

   ☐ Yes ☐ No ☐ No strong opinion

3. Handouts were given you which covered the same material. Were these handouts helpful?

   ☐ Yes ☐ No ☐ No strong opinion

4. This question concerns the duplication of material in the handout and the presentation.

   ☐ I would rather see the presentation only.

   ☐ I would rather read the handout only.

   ☐ I would like to have both the handout and the presentation.

   ☐ I would like some other arrangement. Indicate what.

5. Do you feel that more slide-tape programs should be produced for use in the Aero Labs?

☐ Yes ☐ No ☐ No strong opinion

6. If you answered yes to the previous question, place the numbers 1 through 5 in the following boxes to indicate which of the Aero Labs could profit most by similar slide-tape presentations. (Number 1 indicates highest priority for future programs.)

☐ 2801

☐ 3811 Structures portion

☐ 3811 Dynamics portion

☐ 3851 Remainder of Low Speed portion

☐ 3851 High Speed portion

Questions 7, 8, and 9 pertain to the programs which covered the experiment on pressure distribution over an airfoil.

7. Do you feel that the slide-tape presentation contributed to an understanding of the lab and its objectives?

☐ Yes ☐ No ☐ No strong opinion

8. Did you feel that the quality of this presentation was acceptable when compared with the first programs that you saw?

☐ Yes ☐ No ☐ No strong opinion

9. Part II was an attempt to cover a dull subject; i.e., the derivation of the equations required and the procedures to reduce the data. Did this satisfactorily accomplish its purpose?

☐ Yes ☐ No ☐ No strong opinion

I did not see this particular presentation

10. If you have any comments or suggestions please write them below.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Some of the problems usually associated with laboratory courses are overcrowded conditions, improper briefing of students, unavoidable absence, and the lack of standardization in the course structure.

A fully automatic slide-tape lecture program is an acceptable means of minimizing these problems. These presentations are used to introduce background material of a general nature, presesent instructions for the operation of the necessary equipment, or to brief the students on the

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objectives, procedures, and desired results of a particular experiment.
A major portion of this thesis is devoted to treating the methods used in the preparation of a typical slide-tape lecture presentation. The objective is to provide a listing of important information relevant to producing slide-tape programs. Also included are four slide-tape presentations which were developed for use in the wind-tunnel laboratory course.

Thesis 146745
W222335 Wallace
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Preparation of slide-tape lecture programs for use in aero labotories.